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ABSTRACT

Technology is growing in exponential leaps as capabilities increase and prices decrease. In some cases, advancement occurs so rapidly that, just as one technology becomes known, a succeeding one emerges. Such rapid change introduces a need for frequent reevaluation of equipment and application strategies and of the organizational learning process; it takes considerably more work to get individuals to apply their acquired skills collaboratively than it does to train them singly. It is important for every organization that can benefit from or be affected by technological innovations to attend closely to developments, and to cultivate an appreciation for both the full costs and the replacement costs associated with information technology. Educational institutions in particular must learn to become aware of the true costs of technology and learn the different management styles that emerging technologies demand; Harvard's Office for Information Technology (OIT) serves as an example of this approach. Information technology affords tremendous opportunity to Harvard and other universities, and will consume a significant portion of all faculty operating budgets in the future as universities learn to manage older technologies, while newer technologies, demanding fresh perspectives and approaches from management, are introduced. (KM)

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Every which way one looks, technology is making exponential leaps—up in terms of capability, down in price and size—and all at a pace that hardly allows a given technology to mature before another arrives to replace it. Activity of such magnitude can, but need not, be overwhelming. As with so many things, balance is wanted; in academe, those responsible for promoting enlightened application of new technologies to education must consider the impact, not only on long-standing educational practices and tenets, but also on issues related to organization and management.

Thoughts on emerging technology

Stephen C. Hall, Director, Harvard University Office for Information Technology

Thirty years ago Harvard University had a computer. Twenty years ago it had a dozen computers. The leaps that followed have been exponential, from a dozen to more than two hundred in a decade; from a few hundred to one thousand in less than five years; from one thousand to six thousand in a little more than one year (Figure 1).

Technology growth rates and factors

Harvard, circa 1986, can count a terminal or personal computer for every other person at the University, a pretty fair accounting for a non-technical university and a higher ratio than can be claimed by many computer-intensive universities. Within another decade, Harvard will probably record a one-to-one ratio of people to workstations. We will not be alone; a great many service and business institutions will move toward this same technology-to-people ratio. The computer will become for education and commerce the kind of utility that the telephone became in the 1950s.

How is it that a technology that was just emerging a little more than three decades ago is today growing exponentially? Part of the answer lies in economics. Ten years ago, electrically powered desk calculators sold for more than one hundred dollars. Today, a pocket sized solar powered equivalent of these devices can be had as a premium with a magazine subscription or bought off the shelf for five dollars. The same is true for digital watches. Pricing of electronic appliances—computers as well as calculators and watches—has plummeted with advances in semiconductor technology that have imbued increasingly smaller pieces of silicon with increasingly vaster functionality.

Change is perhaps most evident in the microminiaturization of computational power. The multi-million dollar Mark I computer completed at Harvard in 1943 occupied most of an entire building. Forty years later one thousand times that machine's computing power is contained in portable computers that can be bought for a price ranging from a few hundred to a few thousand dollars. The scale of invention and economy represented by this difference is on the order of six orders of magnitude. Admiral B. R. Inman[1] predicts that "in ten years, at least ten times the computing power of that portable . . . but more likely one hundred times, is going to be found on a chip the size of [a] thumbnail." Developments that will foster another six orders of magnitude reduction in size and economy are already in the laboratory.

Harvard, circa 1986, can count a terminal or personal computer for every other person at the University.

Recently, at a luncheon hosted by the Office for Information Technology's Telecommunications Services Division, Dr. Arno Penzias, Executive Vice President of AT&T's Bell Laboratories, observed that in general predictions about technology end up falling short of actual results, and predictions about the impact of technology usually fall very short. If we're only beginning, halfway up this exponential technological growth curve, to discern the effects of its impact, how are we to imagine what the rest of the

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climb holds in store? If we assess what technology has brought us to date, we have more cause to be rosy in our anticipation than negative.

Tools of the service economy: the differentiation of technologies

The shift in the economy of the United States from an agricultural to an industrial to a service base has been thoroughly documented. Agriculture, which once accounted for seventy percent of the U.S. economy, today accounts for about two percent. The industrial preeminence of more recent history has waned as manufacturing has shifted abroad in search of cheaper labor. The service economy that has emerged in its stead has done so with help from the economies of scale and integration that have been realized in the devices of technology. The computer and the international telecommunications network are the future tools of the emerging service economy just as the tractor was the tool for agriculture and the assembly line the tool for industry.

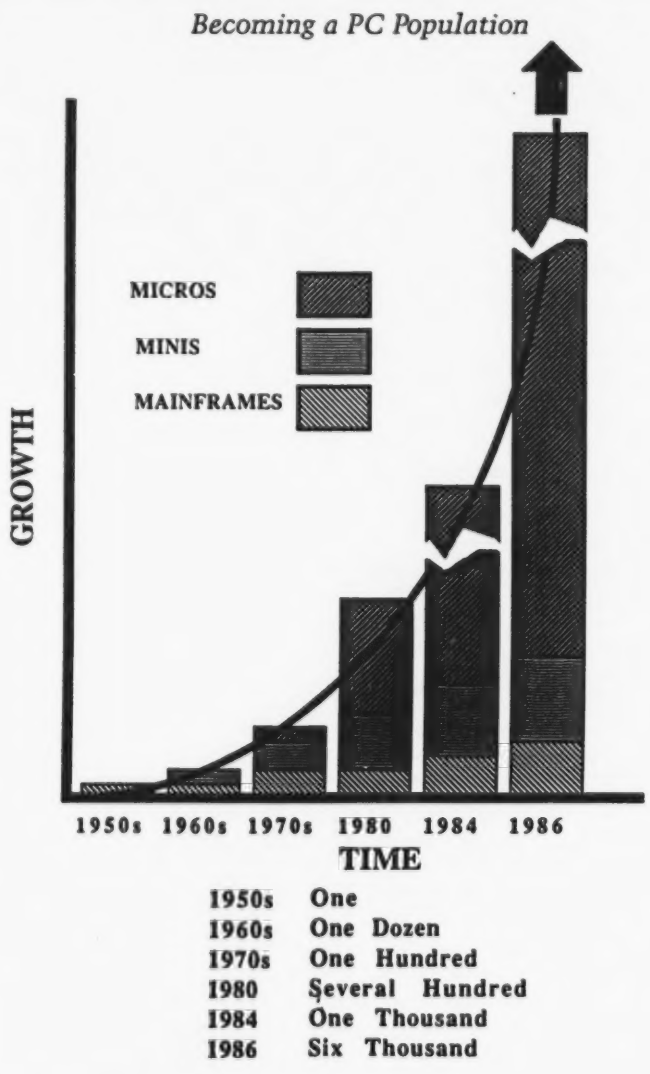

Figure 1: Harvard Computer Census

The most notable aspect of the shift to a service economy has been its rapidity. Agricultural practices in the U.S. changed gradually over hundreds of years. The rise (and slip) of U.S. industry occupied little more than half of one century. The pitched onset of the service economy has happened overnight by comparison with these. Many whose youth was given to forging the tools that enabled this shift can, as middle-aged observers, trace the differentiation of technologies that has accompanied its realization.

The early computer workhorses of the service economy were mainframe computers and computer languages, such as COBOL and FORTRAN, that facilitated development of information processing systems for business and research. In the 1960s remote terminals and telecommunications began to foster distribution of the information resource that resided in mainframe computers. In the 1980s, in the scaling down of the computing resource and refinements in telecommunications networking, we have the precursors of more fundamental changes in the distribution of and access to computerized information.

Standing on the brink of cooperative cultivation and distribution of information via nationwide networks for data, video, and voice, we are but thirty years removed from those first workhorses that enabled institutions and organizations to begin automating the farming of their own little plots of information. With the divestiture of the Bell system and the current disposition toward deregulation, we can forecast that the evolving network will take a different form from that of the formerly monopolized telephone network.

We are accustomed to seeing older technologies coexist with newer. The horse did not disappear with the invention of the automobile. In the railroad industry, steam power coexisted with diesel before being almost entirely supplanted by it. With computing technology, the same coexistence is in evidence, but the time frame has been drastically compressed.

Fourth and fifth generation lan-

CHARTS AND GRAPHS BY CHARLES GALLAGHER/OFFICE FOR INFORMATION TECHNOLOGY

guages, the microcomputer, and telecommunications networks have arrived seemingly on the heels of earlier generation languages and the mainframe computers they run on. The period of discontinuity that has ensued is shown graphically in Figure 2. To explain the circumstance whereby just as one starts to use a technology a succeeding one emerges, Girifalco[2] offered the analogy of the jet engine which, though a technological improvement over the internal combustion engine, did not entirely replace it because the latter remained more efficient for some applications. So, too, do we continue to use mainframe and minicomputers even as microcomputer and workstation populations swell and telecommunications networks spread.

The same kind of overlap has occurred with software. Development of higher level languages was driven initially by issues of economics and productivity in large institutions that had come to rely heavily on computers for data processing. Fourth generation languages combined transaction processing capabilities well established in third generation languages with enhanced database definition to provide a more generalized application. For a given function, such as report writing, a fourth generation language requires less copious and precise instruction from its user; vendors refer to the "English language-like" *user interfaces* of system products developed with fourth generation languages.

An emerging fifth generation of languages is further simplifying the user interface. These languages incorporate components derived from artificial intelligence (AI) research to provide "push-button" access to their information stores. To a user, the mechanism has the aspect of magic, but, in fact, there is a formidable complexity underlying such systems. Development of fifth generation languages is occurring primarily at universities where most of the research that yielded their AI substrate has been conducted.

The difference between fourth and fifth generation languages is like the difference between knowledge and experience in humans.

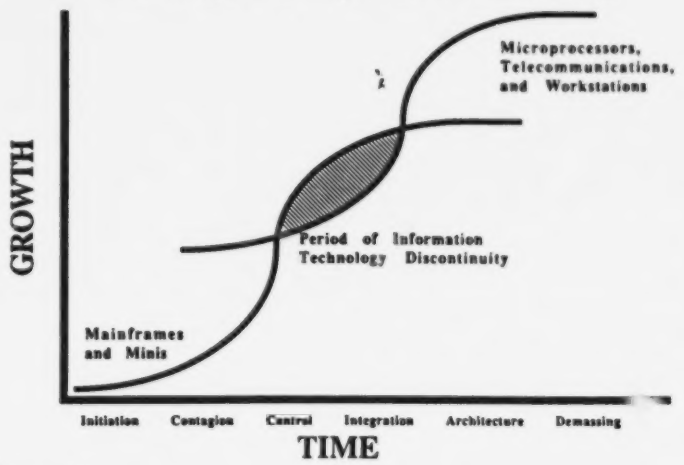

Figure 2:
Information Technology Growth and Replacement

Human knowledge, like the content of a fourth generation language database, is primarily data. All a database can do is report selections from that data on request. Knowledge that is experienced in a meaningful way constitutes thinking, and this is the kind of activity that systems developed with fifth generation languages try to capture. Hence, instead of databases we have knowledge bases, which are essentially codifications of some body of human experience. Because such codification is extremely labor-intensive and human experience is so vast, the domains of knowledge bases tend to be highly constrained.

Complex, dynamic, data intensive activities like weather modelling and forecasting will consume as much computing power as we can throw at them for the foreseeable future.

Fourth and fifth generation languages have less in common than they might. The two generations have not taken advantage of one another to any significant extent, a situation that derives, in part, from the divergent backgrounds of their developers. Bringing these people together to build more bridges between their respective generations could push on the limits imposed on further development by the labor-intensiveness of the activities.

In moving toward the notion of parallel processes in thinking, artificial intelligence has suggested a technique for overcoming limits being approached in computing hardware. How fast computers can process data is limited by existing circuit and switching speeds and, ultimately, by the speed of light. By breaking problems up into multiple parts and processing the parts in separate processors—so called parallel processing—far greater overall speeds can be achieved.

Every generation of hardware has its supercomputers, computers especially designed and programmed for extraordinarily fast processing of very large amounts of data. The Mark I was the supercomputer of its time. Today, the supercomputers of Control Data Corporation and Cray are being joined by entries from Japanese computer manufacturers. Complex, dynamic, data-intensive activities like weather modelling and fore-

casting will consume as much computing power as we can throw at them for the foreseeable future, ensuring that subsequent generations will also have their supercomputers, but we can expect, and we are already beginning to see, reductions in size in the supercomputer class of machines.

Hallmark though it is of this era of emerging technologies, the microcomputer is but the general purpose computer that the mainframe was only a few years ago. Microcomputer applications are still relatively primitive, in many ways like the general purpose applications of early mainframes. The micro's most remarkable aspects are its size and cost, which create as great a potential for everyone to have a general purpose computer as an earlier technology created for everyone to own a typewriter.

An explosion of possibilities followed the development of the mainframe computer, and an equivalent or greater explosion can be expected to accompany continued development of the microcomputer. Even now, multiplication of applications for the general purpose micro is being accompanied by a certain amount of hardware specialization; high-end dedicated microcomputers, frequently called workstations, have already cropped up in publishing in the form of stand-alone page composition systems, in engineering in computer-aided design/computer-aided manufacturing (CAD/CAM) systems, and in banking in automated teller machines (ATM). Within ten years, complex secretarial and financial analyst workstations will be a commonplace, and employees hired for these positions will expect their work environment to include them.

The emerging technologies that will tie everything, or at least a great deal of it, together are networking and public databases.

Analog traffic on the international telecommunications networks is declining rapidly. Conversion of analog signals to digital for transmission over high-speed long distance digital circuits is being done closer and closer to the end points of the network, even in the telephone handset itself. Modems (for modulator/demodulator) are being supplanted by codecs (for coder/decoder), microchips that create digital bits streams out of voice signals at the handset or switch and pass digital transmissions between communicating computers, without modulating or demodulating them, over entirely digital networks.

As with digital sound systems, the components at the ends of the increasingly digital networks don't look, or seem to operate, much differently from what we're used to. We pick up an instrument that we know to be a telephone or switch on a device that plays records, cassettes, or compact disks and talk or listen as we always have with hardly a thought for underlying improvements in quality and reliability or extended functionality.

As remarkable as they might seem now, we will also come to take for granted personal workstations capable of recording incoming data, both voice and text, on disk and play it out, upon request, in whichever mode we choose, voice as voice *or* text, text as text *or* in a synthesized voice. Digital Equipment Corporation already has equipment that will do the latter, but the capability to routinely and economically transform voice messages into text awaits further advances in voice recognition technology.

For most of recorded history, libraries have provided the principal medium for sharing the growing body of human knowledge, but with the growth of international telecommunications networks and creation of vast integrated public databases increasing amounts of human knowledge will become accessible on-line.

For most of recorded history, libraries have provided the principal medium for sharing the growing body of human knowledge. With tightening and standardization of the international telecommunications networks and creation of vast integrated public databases, increasing amounts of human knowledge will become accessible *on-line*. Moreover, computer knowledge bases built with fifth generation languages will have the potential to make available forms of human knowledge not amenable to print distribution; expert systems created with artificial intelligence techniques can open the doors to knowledge bases that today can be accessed only by personal interaction with their human repositories.

Furthermore, the systems by which such knowledge can be codified demand that the validity of concepts to be imparted to the knowledge base be tested and provide tools for debugging those concepts. The rigor of program logic requires that knowledge funneled through it be thought through much more thoroughly than if it were to be set down in the chapter of a printed book. Whereas a book that presents faulty concepts can be read, a computer resident knowledge base built with faulty concepts will simply not work.

Emerging technology issues: demand side

Organizational learning

Noted consultants, scholars, and planners Nolan and Girifalco have charted the growth over time and overlap of succeeding technologies (Figure 2). Such rapid change introduces a need for frequent reevaluation of equipment and application strategies and of the organizational learning process. Richard Nolan[3] has observed that technology is absorbed by organizations in stages or in a measured way, much as individuals learn music through protracted practice. It takes considerably more work to get individuals to apply their acquired skills collaboratively, to play together as an orchestra, for example. Similarly, individuals can be trained in the use

of the information resource that sits on their desks in the form a personal computer, but to orchestrate the organization's use of technology to help improve what the organization does is a task of a different order.

Nolan[4] has identified six stages in the growth of computing in an organization. The first four, *initiation, contagion, control,* and *integration,* follow the first of the two discontinuous S-curves in Figure 2. Computing typically is introduced to an organization in a particular application (initiation). With recognition of the generalizability of the computing resource, growth of applications subsequently explodes (contagion), whereupon, usually for budgetary reasons, an effort is made to control further growth (control). The period of discontinuity at which an attempt is made to integrate the mature information resource into the organization (integration) typically entails an accompanying assimilation of advances in hardware. Currently, this is taking the form of integrating a relatively mature data processing technology with a relatively immature microcomputer technology.

The fifth stage, developing an *architecture,* relates to creating an organizational concept of data administration, in Nolan's words, of "designing a computer architecture for doing business."[5] Emphasis at this stage is on managing distributed responsibilities for a mix of centralized and decentralized information resources. Reviving and sustaining innovation without sacrificing the balance struck among this mix of resources constitutes the sixth stage, *demassing.* By this point, the information resource should exhibit the cohesiveness of a symphony orchestra; the applications portfolio should be essentially complete, and the creation and exchange of information among the various pieces should follow the score that describes the natural flow of information within the organization.

Much of contemporary management is ambivalent, not only about the issue of orchestration, but even about the very deployment of the information resource. Not that this should come as a surprise; it has often been the fate of invention to go underappreciated for long periods of time. Witness the steam engine, an appreciation for the utility of which lagged nearly a millennium behind its conception.

Though there is ample precedent for overlooking the value of a technology, to do so can be costly, especially given the compressed time frames that are the order of the day. Lockheed Corporation's decision, some years back, to develop the prop jet was a case of ploughing a familiar field while Boeing, in betting on the less tried jet engine, broke new ground. Lockheed's shortsightedness had to be funded by taxpayers through government loans. In the world of information processing, the personal computer is the jet engine, the mainframe the prop jet, and, just as the jet revolutionized transportation, relegating the prop jet to performing yeoman service for numerous small feeder lines, so the personal computer is revolutionizing the service industry and consigning the mainframe to a supporting role in network and file service.

We'll never have a nationwide network for the transport of voice, data, and video signals without a set of standards for the network, the equipment that plugs into it, and the software that runs on that equipment.

Recognizing and managing the benefits

To speak of the origination, processing, and distribution of information as the business of computing technology is to vastly underrate its potential. Education relies on the transfer not only of information, but also of the skills and intuitions that facilitate its comprehension. The utility of computers goes well beyond the creation, manipulation, and exchange of words and numbers. Using a video display, a computer can simulate complex events and phenomena that would be impractical or impossible to produce and observe in the physical world.

As a student in music composition, I had to hunt and peck at the keys of a traditional piano to hear what I had composed. I didn't have the talent to play it very well. Today students can hunt and peck at the keys of a personal computer keyboard to help them play out their ideas. Appropriately equipped and programmed, the personal computer can even play the musical composition so the student can hear it in integrated form. I wish that I could have ended my compositions with a further keystroke and heard my aspiring masterpieces played back to me. Such utility can go a long way toward encouraging the musically inclined but less nimble-fingered among us not to forsake our ambitions. It can promote the development of a musician in one who might otherwise not have been one.

This is but one testimonial to the pedagogical value of the computer in the humanities. Word processing, by reducing resistance to revision, is helping many students to improve their writing. Computer-aided instruction programs are helping students to learn new languages in a structured, interactive way. Testimonials to the efficacy of the computer in research and science education are abundant, as they are in organizational administration and commerce.

At Tufts University, students are using personal computers and a Software Studio to help them understand concepts in fields like computer science. An educational modelling program enables students to observe the internal execution of a computer program at a variety of levels—functional, computational, and circuit—presented in a simple graphic manner rather like a video game. Because it provides an instrument that has utility for arranging and composing the concepts under study, as well as for playing them through, George Smith, Co-Director of the Software Studio, uses the analogy that their mission is to create "conceptual pianos" using microcomputers and software.

A wave is building, but we can now only guess at its eventual proportions. Just as there are obstacles, often unseen, that impede development of the waves that crash on our shores, so there are inhibitors to the wave of computer technology that is, for better or worse, but probably for better, breaking upon us. One of these is lack of standards.

Emerging technology issues: supply side

Standards

Whatever else might be said about the monopoly that created the Bell system, it gave us a network that not only works, but has set a standard of excellence. Incompatibility of software and communications interfaces is a bane on the integration of information processing. We'll never have a nationwide network for the transport of voice, data, and video signals without a set of standards for the network, the equipment that plugs into it, and the software that runs on that equipment. There are indications that manufacturers have recognized the need for, and are beginning to cooperate on the development of, some level of standardization.

The principal hope for an integrated network is the Integrated Services Digital Network, or ISDN, the promise of which is common network access for data, video, and voice traffic. John Doggett of the Bank of Boston, notes that trial implementations of ISDN are underway in the corporate world, but he sets large scale penetration of the residential market about ten years away[6]. Wayne Hall, of Digital Equipment Corporation, agrees with Doggett's time frame, but worries lest the eventual ISDN not be the same standard in all places, that there might, for example, be a U.S. ISDN and a European ISDN[7]. At present, the standard is not sufficiently well defined for any manufacturer to realistically claim compatibility with it.

Utility

Only when manufacturers have provided the underpinnings, in the form of the requisite standardization, can we hope to have information utilities of the scope of the utilities that today supply power and water and regulate the flow of traffic. Imagine having to take into consideration in the purchase of a car its compatibility with the highway system—whether it has a range of speed and power sufficient for every grade that it might encounter, whether its suspension system is adequate for all road surfaces, whether its steering will enable it to navigate every expressway ramp. Such considerations seem absurd. You might consider each of these things in the purchase of a car, but not for reasons of compatibility; you might consider suspension from the standpoint of comfort and safety, speed and power in light of the kind of driving you do, and steering on the basis of feel and response. But a certain level of standardization among auto makers and highway builders insures that any car you buy will operate on any highway you care to drive it on. That you can walk into any department store in any state and buy an appliance without regard to the manufacturer and expect to take it home and plug it in and use it is also due to standardization.

Educators are seldom equipped to appreciate the costs associated, for example, with corporate benevolence; the old adage about Greeks bearing gifts might be prudently recalled today when the bearers are beneficent corporations.

Public databases: information sharing

When the necessary standards have been established by the computer and communications industries, we will begin to see developed for the handling of information equivalents of the kinds of public utilities discussed above. Program and data utilities will provide pre-packaged functionality in different realms. Administrative and library utilities come readily to mind. We are already using their prototypes. Some numeric and bibliographic databases can be called and interrogated by means of a touch-tone phone, while interaction with others requires the use of a terminal or personal computer with communications software. But the future student or consumer will need more than one communications package to interrogate different databases. The ability to build universally accessible utilities that can dispense information in a form that is immediately useable by the consumer is still pretty abstract. The day of plug-in information utilities is in the offing, but what we have at the moment is a situation reminiscent of the early days of television. I call it the Alabama problem in acknowledgement of an early experience of my wife, who took her television set to Alabama, plugged it in, and invited the neighborhood children in, only to see video "noise." Nobody was broadcasting in the state at that time.

We have things to plug in, but the things we can plug them into are far from public information utilities. Besides standardization, the man-machine-interface cries for attention. We need efficient, elegant examples of data/video/voice synthesis. Resource requirements will dictate that development take place in institutions which will slow progress somewhat. Budding enterprises nurtured by institutions take a longer time to blossom because institutions are collections of people and, as we noted earlier, it takes much longer to train people to work in concert than it does to train them for individual pursuits.

Limits to imagination

Such impediments foster an inclination to restrain our imaginations; hence, we are prone to conservative estimates of what a technology can really do for us. Early prognostications for electronic publishing focused on refinements of and enhancements to traditional publishing processes. Few anticipated

the impact at the other end—that the technology could put publishing capability in the hands of the author and completely restructure the industry.

It is important for every organization that can benefit from or be affected by technological innovation to attend closely and carefully to developments. Organizational learning is a complex activity that takes time and demands attention from the top; both must be allotted in sufficient amounts if an organization is not only not to be bypassed or rendered ineffectual by technological innovation, but also avoid pitfalls that can accompany adoption of even appropriate technologies. Organizations need to cultivate an appreciation for both the full costs and the replacement costs associated with information technology.

Full costs

Educational institutions are particularly susceptible to a failure to comprehend the true costs associated with the devices of technology. Educators are seldom equipped to appreciate the costs associated, for example, with corporate benevolence. The old adage about Greeks bearing gifts might be prudently recalled today when the bearers are beneficent corporations. Though they are not, as they were with the Trojan horse, malevolent, there are costs associated with the gleaming machinery of computing that manufacturers push through the portals of colleges and universities. A school might accept, for example, a gift of a multi-million dollar mainframe computer only to discover, over time, that the hardware represents only about ten percent of the total cost incurred by using it, and have to raise the ninety percent required to pay for space, essential additional equipment, staffing, development, software, maintenance, and, all too soon, upgrades to or replacement of the gift itself. The problem is a sleeper, and many, like the Trojans, get caught.

The lack of appreciation for the full costs of information technology in evidence at the macro level today will begin to become evident at the micro level tomorrow. To those who fail to look beyond the initial cash outlay associated with the purchase of a personal computer and software, later costs—in time and money—related to operation (housekeeping chores such as backing up files and maintaining directories and costly connect time to dial-up data services), maintenance (care and feeding of hardware and floppy disks and renewal of service contracts), development (attaining proficiency with software and adding needed components to the hardware), and replacement (of aging or obsolete software and hardware) will come as a rude awakening.

Emerging technologies must be managed differently; entrepreneurial, traditional data processing, retail, and utility management all represent management styles that are used successfully in different cases.

Management style

As organizations learn how to appropriate the tools of information technology and effectively integrate them into their daily business, the style and delivery of information services will change. Emerging technologies must be managed differently; entrepreneurial, traditional data processing, retail, and utility management all represent management styles that are used successfully in different cases.

When computers were thought of as technical things, when it was assumed that you had to know how to program in order to accomplish anything useful with them, it was necessary to rely on specialists or service organizations to help move development along. This is what Harvard's Office for Information Technology (OIT) was created to do. With the goal of doing all things for all users, such information technology organizations typically broke computing down into a number of sub-specialties.

The OIT organization attempts to use the most appropriate management style for each of its different types of services:

- the Applications Development Division functions as a custom contractor;
- the Administration and Planning Division is patterned after a consulting service;
- Computing and Information Utilities operates as an information utility;
- Instructional Television, in proselytizing for a much underappreciated and underutilized emerging technology, follows a "missionary" approach;
- the Technology Product Center is styled after retail and service outlets, such as department stores;
- and the Telecommunications Services Division functions as a public utility.

OIT is also engaging in entrepreneurial activities, testing the market with start-up ventures like its media conversion service for rendering floppy disk files created on one machine compatible with another. In the wide world, one can today buy many information products in department stores; OIT's retail outlet is the Technology Product Center, with offices and showrooms in Cambridge and in the Medical Area in Boston.

More than the service organizations themselves are destined to change as technological progress takes its course. In education, we can certainly expect faculties to endure. But we can also expect to see more interdisciplinary activities and, with less labor intensiveness in the administration, diversion of more human resources into direct academic support. At Harvard, we can expect the independent departments (like tubs, remaining all on their own bottoms), to look for more ways to share their information resources, thereby exerting pressure on individuals and departments to create quality information resources worth sharing.

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Implementation, or, Getting on with it

Information technology affords tremendous opportunity to Harvard and other universities, particularly in the areas of instruction and libraries. Appreciation of it can perhaps best begin with the people who make up the institutions asking themselves, "What is the most important thing I do or service I provide, and what am I doing to enhance it with information technology applications?"

There are a lot of computers at Harvard on which a lot of people are doing a lot of different things, and that's good. Many institutions would probably like to trade us one for one for resources. But how are we doing in the broader context? I have referred repeatedly to the difficulty of orchestrating individual skills in collaborative activities. Utility is the glue that makes technology stick, but the greatest impact will be achieved when utility can be shared, when a mechanism exists for sharing data and the tools to manipulate it among the broadest possible population.

If we might narrow our focus for a moment, the really promising thing about emerging technologies for Harvard is their distributed and personalized nature. Large computers demand a certain amount of centralization, a difficult thing to achieve at an institution whose tradition is steeped in decentralization. Because Harvard departments are fractional, rather than mega, they are better accommodated by the newer micro technologies.

Technology isn't free, but it's getting cheaper all the time. A natural environment in which one can find what one needs, in which everything is running toward an appropriate destination, isn't all that improbable in the world of information. Neither is it around the corner, but with supercomputers shrinking to the size of contemporary PCs, and expert systems people working on the codification of experiential knowledge in such fields as law and literature, it becomes easier to entertain prospects for change of a far more radical nature than that we have witnessed to date. Harvard faculty possess an extraordinary amount of expertise; we can expect substantial future value and contributions in software to flow from this resource.

The really promising thing about emerging technologies for Harvard is their distributed and personalized nature; large computers demand a certain amount of centralization, a difficult thing to achieve at an institution whose tradition is steeped in decentralization.

The new information resources afforded universities will be more robust and more shareable, but their very pervasiveness will make them more expensive despite the declining cost of the technologies themselves. Information technology will consume a significant percentage of all faculty operating budgets. In this and other ways it will come to resemble an institution's physical plant. As the state of the granite and brick of older buildings must be attended to even as newer edifices of steel and glass are erected nearby, so too will older technologies have to continue to be managed even as newer technologies, demanding fresh perspectives and approaches from management, are introduced.

We're all familiar with early nineteen hundreds visions of the technology of the future. They frequently present a picture of a living room appointed with all manner of unnecessarily complex, Rube Goldberg devices. More often, technology is just assimilated; the added service and value it introduces in various realms become simply a part of the overall quality of life. I expect that Harvard, as it has so many other things, will absorb information technology very well. I expect that people will continue to read books by the fire; but coming, perhaps, to an obscure reference, rather than noting, mentally or on a convenient scrap of paper, the intention to look it up, they might push a button on the arm of their chair or pick up a sleek plastic device, connect with a remote database through a university or national network, and, in the next moment, using multiple media, peruse the source of the citation to the crackling of the logs in the fireplace.

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